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STUDY OF FUTURE ANTENNA TECHNOLOGIES FOR SHIPBOARD SATELLITE COMMUNICATIONS

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DEFENCE RESEARCH ESTABLISHMENT OTTAWA

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Abstract

The purpose of this report is to document a study commissioned to Defence Research Establishment Ottawa (DREO) by Director Maritime Ship Support (DMSS) in the area of future naval satellite communications (satcom) for the Canadian Navy. The study investigated possible technology gaps in the area of satellite antenna systems for military applications, concentrating on the difficulty of installing large antenna systems on smaller size ships.

With the advent of numerous new satellite services, both commercial and military, and the merging of the communications media (information highway), the demand for more satcom capacity on ships is increasing rapidly. Because of the limitations in size and weight, several bands and several beams could be integrated together in a single antenna platform. All these signals would be connected (remotely) to various terminals dispersed across the ship. Reflector antennas and phased array antennas are the two main technologies to help achieve this goal.

The present state-of-the-art for reflectors and phased arrays in the area of multi-band and/or multi-beam is not mature yet. The major limitations are cost and complexity. However, since this area has become popular only recently, there is ample room for rapid improvements and possible breakthroughs.

Résumé

Le but de ce rapport est de documenter une étude sur les communications satellites futures pour la Marine Canadienne. Le mandat pour cette recherche a été confié au Centre de Recherches pour la Défense Ottawa (CRDO) par le Directeur – Soutien aux Navires (DSN). Cette étude examine les besoins technologiques à venir dans le domaine des systèmes d'antennes pour communications par satellites, particulièrement les difficultés reliées à l'installation de larges systèmes d'antennes sur de petits navires.

Avec l'arrivée constante de nouveaux services par satellite, militaires et civils, et la convergence des médias de communications (l'Autoroute Informatique), la demande de capacité croît rapidement. A cause des limitations de poids et de grandeur, il serait avantageux de combiner sur une seule plate-forme d'antenne plusieurs bandes de fréquences et plusieurs faisceaux. Tous ces signaux pourraient être connectés à plusieurs terminaux répartis à travers le navire. Les antennes réflecteurs et les antennes à réseaux sont les deux principales technologies de base qui permettraient d'atteindre ce but.

L'état actuel de la technique pour les antennes réflecteurs et les antennes à réseaux n'est pas mature dans le domaine des bandes et faisceaux multiples. Les principaux obstacles sont le coût et la complexité. Cependant, puisque ce domaine n'a attiré l'attention que tout récemment, il est possible d'espérer un progrès rapide et même des découvertes capitales.

Executive Summary

The purpose of this report is to document a study commissioned to Defence Research Establishment Ottawa (DREO) by Director Maritime Ship Support (DMSS) in the area of future naval satellite communications (satcom) for the Canadian Navy. The study investigated possible technology gaps in the area of satellite antenna systems for military applications, concentrating on the difficulty of installing large antenna systems on smaller size ships.

With the advent of many new satellite services and the merging of communications media (information highway), satellite communications are growing very rapidly. Canadian ships need access to satcom services common with their allies and also to commercial services.

An important problem faced by our Navy regarding all these new services is how to get them all on-board in the limited space available taking into account all the other restrictions imposed by the ship environment. One approach is to combine several services into a single terminal antenna. This means that the antenna must be multi-band and/or multi-beam. In this report we looked at geosynchronous (and geostationary) services only and how to access more of them.

The two main technologies for multi-band and multi-beam antennas are reflectors and phased arrays. The table below show a comparison between the two.

	Pro	Con
Reflector	• Inexpensive • Wider bandwidth • More mature technology • Easier to repair	• Bulkier, heavier • Slower beam steering
Phased Array	• Lighter • More agile (fast) beams • Low profile • Conformal • Low weight	• Expensive • Sensitive to internal intermodulation • Difficult to design for wideband and/or multi-band • More susceptible to EMI

With reflector antennas, it is possible to combine several bands and both polarizations into a single feed. Frequency selective surfaces (FSSs) can also be used to combine even more bands. If more than one geosynchronous satellite has to be accessed simultaneously, it is possible to conceive a reflector that has one feed pointing at each satellite.

Phased array antennas in their most exotic implementations can form and steer several beams in different directions at different frequencies. Their main disadvantage is

cost. However, with the rapid advance in phased array technology, it is foreseeable that phased arrays will have more and more applications in communications.

This report looked at multi-band reflectors, multi-beam reflectors, and phased array antennas. In the table below is a short summary of the areas of investigation with some indication of the time frame required to develop the technology for specific applications. The R&D effort should focus on the specific needs of the Canadian Navy that cannot be satisfied by the commercial industry or our Allies effort.

Functionality	**Reflector (or lens)**	**Phased Array**
Single-band, single-beam	current technology	3 years & up
Multi-band	1 to 5 years	5 years & up
Multi-beam	1 to 3 years	5 years & up
Multi-band and multi-beam	3 to 7 years	7 years & up

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1.0 Introduction

1.1 Objectives of this Report.

The purpose of this report is to document a study commissioned to Defence Research Establishment Ottawa (DREO) by Director Maritime Ship Support (DMSS) in the area of future naval satellite communications (satcom) for the Canadian Navy. The study investigated possible technology gaps in the area of satellite antenna systems for military applications, concentrating on the difficulty of installing large antenna systems on smaller size ships.

This report, after defining in more details the problem, looks in chapter 2 at our allies' use of naval military satellite communication (milsatcom). In addition, the report identifies their future research and development (R&D) activities in antenna subsystems. Chapter 3 presents the state-of-the-art in multi-band and multi-beam reflector antennas. Chapter 4 investigates phased array antennas. Recommendations for future study are given in chapter 5 and chapter 6 concludes this report.

1.2 Future Satcom Services.

It is expected that future naval satcom at sea will be equally divided between commercial service providers and military service providers. To date the Canadian military makes extensive use of commercial providers such as INMARSAT and INTELSAT. The use of these and other commercial systems are anticipated to grow with time. However, existing military satcom services are limited and are usually restricted to joint operations such as the Navy use of FLTSATCOM. Full access to MILSATCOM will be provided by the Canadian Military Satellite Communications Project through an anticipated agreement with the US. However, access to these services is not expected to start until early into the next century. Until full access to the US military systems are provided, interim capability is possible with both the UK Skynet satellites and the NATO satellites. The satcom industry is experiencing a rapid growth as more and varied services are being provided. This will provide both enhanced capability and challenges to our Navy on the Information Highway.

1.3 Deficiencies and Requirements

The three major requirements for ship satcom systems are:

- Interoperability with our military Allies (mainly US, UK and NATO)
- Access to commercial systems
- Availability of multiple shipboard services

Of the three major requirement stated above the most difficult to implement is the third, availability of all the desired services into a single relatively small

ship. It is the most difficult because a custom solution will be required in several cases and a Canadian capability in the appropriate technologies will be needed.

The commercial industry will fund most of the R&D required to field commercial systems for commercial markets, including the antenna system. However, they will not address the problem of implementing these services on the more hostile environment of a military ship. Some of these problems will be solved by our allies who require similar capabilities for their navies. But Canadian ships are typically smaller in size and in numbers, which has a strong impact on how satcom is implemented on board. This means that there are problems that are typically Canadian that will need Canadian solutions.

1.4 Present Systems

Allied shipborne satcom systems are examined in Chapter 2 along with future directions. Before we discuss what our allies use it is important to examine the type of ship in the Canadian navy and some of the constraints on the satcom terminal. One of our most recent ship acquisition is the Canadian Patrol Frigate (shown in Figure 1). Although, it is seen in the CF Navy as a "large" ship, there in not much space available for terminals. Also, weight above the waterline is always undesirable; a terminal antenna with its inertial platform often weights over 1000 pounds.

One feature of naval satcom is the use of antenna diversity to eliminate the obstruction of the ship's superstructure. Antenna diversity is the concept where two antennas, situated in different locations, track the same satellite and the best signal is selected. In addition to the two separate antenna subsystems, two sets of cables, fibers, or waveguide runs are also required to feed the signals to and from the terminal. The low-noise amplifier (LNA) and the high power amplifier (HPA) are co-located with the antenna to reduce loss in the system. The connections between LNAs, HPAs and the antennas are through coaxial cables or waveguides and are usually short. The connections between the antenna sub-systems and the rest of the terminals are best made through optical fibers because they are insensitive to electromagnetic interference. If travelling wave tube amplifiers (TWTAs) or Klystrons are used as the HPA then they must be located inside the ship structure. Connection between the antenna and electronics is then made with waveguide.

1.5 Technical Solutions

To provide a complete solution for the Canadian Naval requirements, satcom terminals should be expanded from the current single-frequency band (transmit/receive) and single service to support:

- several frequency bands, switchable or simultaneous
- several satellite access, simultaneous or not
- a combination of the above

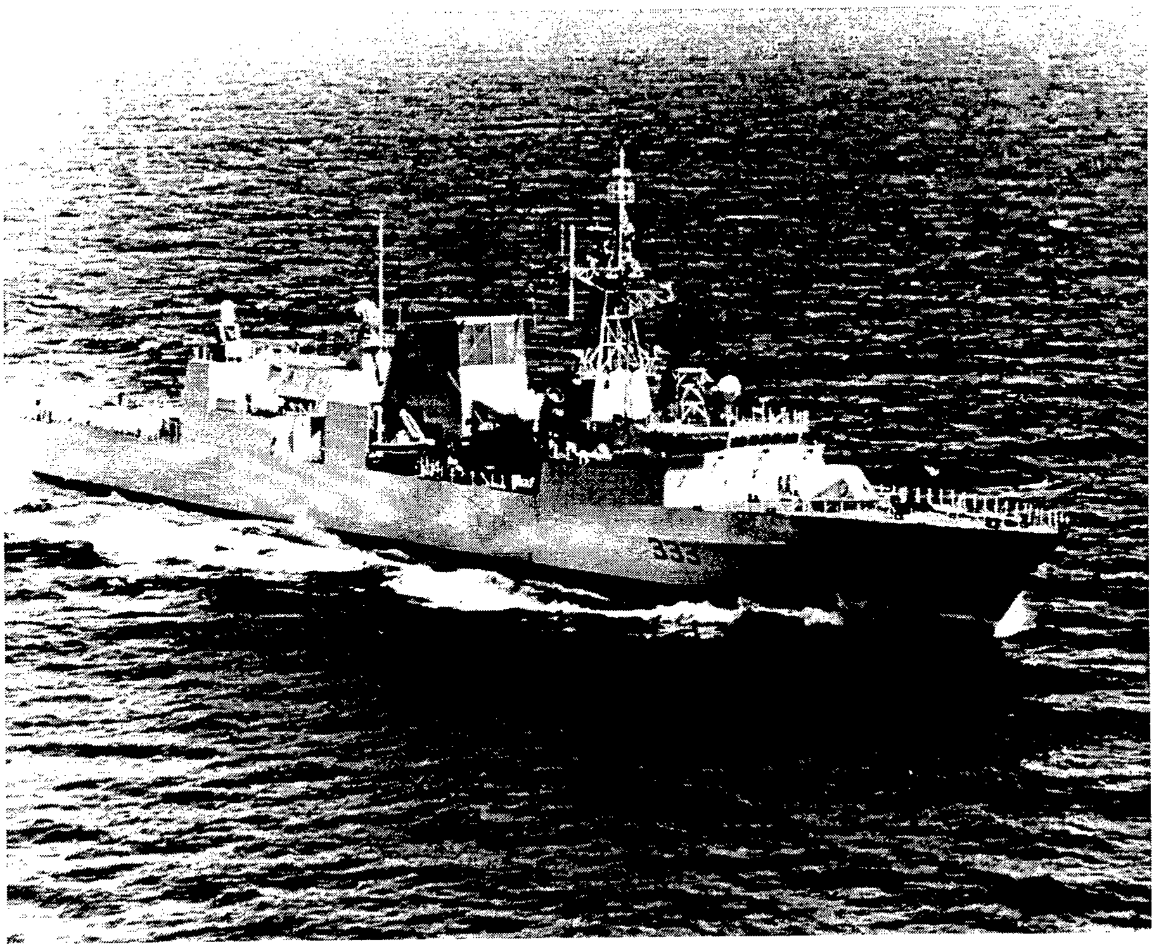

Figure 1. Canadian Patrol Frigate: HMCS Toronto.

It would be highly desirable to combine several services into one terminal by having multi-band antennas. To use different satellites, a multi-beam antenna that will point a beam at each satellite of interest for simultaneous communications is desirable. There are two main antenna technologies that can support these kinds of applications: reflector (or lens) antennas and phased array antennas. In this report, reflectors are investigated in chapter 3 and phased arrays in chapter 4.

1.6 Shipboard Antenna Environment

The ship environment is unique. P.E. Law[1] described military antennas on US ships, and in another book[2], he described the electromagnetic environment special to Navy ships. When investigating satcom systems, the parameters below must be considered. They are sufficiently different to make antennas for the Navy quite different from antennas for the Army or the Air Force.

- salt
- water
- radio frequency interference (RFI)
- superstructure blockage

- movement
- weather
- size (compared to Allies' ships, Canadian Naval ships are relatively small, 150-300 feet)
- asymmetric data rates (ships receive more than they transmit)

1.7 Technical Definitions

1.7.1 Multi-band antenna

Most communications terminals have 2 frequency bands: one for transmitting (Tx) and one for receiving (Rx). The 2 bands are usually not adjacent. The terminal antenna may have a single band that overlaps the 2 terminal communications bands or it may have 2 separate bands, one that includes the Tx band and the other the Rx band. Therefore, the antenna can be single band or multi-band for the same terminal.

A terminal that can use more than one pair of Tx-Rx bands is called a multi-band terminal. The terminal antenna can have a single wide band that covers all of the terminal bands or it can have several bands. The exact implementation depends in part on the frequencies of the bands.

In the literature, "multi-band" antenna can refer to different things, although related. In this report, a "multi-band antenna" refers only to an antenna belonging to a multi-band terminal, whether the antenna itself operates over a single wide band or multiple narrower bands.

1.7.2 Multi-beam antenna

A multi-beam antenna has 2 or more beams that may point in different directions. In most cases, each beam is actually made of a pair of Tx-Rx beams pointing in the same direction. In communications, the Tx beam and the Rx beam almost always point in the same direction, i.e. same satellite. Therefore, in this report, a pair of Tx-Rx beams will be referred to as a beam.

The beams of a multi-beam antenna are not necessarily all active simultaneously, depending on the type of antennas. Typically, when the beams are electronically scanned, they are all active simultaneously. However, if the beams are fixed, there is usually a large number of possible beams but only a subset can be turned on at any one time.

1.7.3 Reflector Antenna

In its most common implementation, a reflector antenna is made of a parabolic reflector with an antenna feed (see Figure 5). In receive mode, the reflector focuses an incoming plane wave from a given direction into the feed. In transmit mode, the signal radiated by the feed is focused by the parabolic reflector into a narrow beam. The beamwidth depends on the reflector size and the frequency. The larger the reflector and the higher frequency, the narrower the beamwidth becomes. For a given reflector and

feed, at a given frequency, the beamwidth and polarization are the same whether the antenna is used in receive or transmit mode (reciprocity theorem).

1.7.4 Dielectric Lens Antenna

A lens antenna is very similar in operation to a reflector antenna. The signal from the feed is focused through a dielectric lens instead of being reflected by a metal reflector (see Figure 7). Because of the bulk and weight of the lens, lens antennas are rarely used below 30 GHz except in low-gain designs. In this report, lenses are not mentioned much but most reflector designs can also be implemented with lenses if the lens does not have to be more than approximately 30 cm.

1.7.5 Phased Array Antenna

A phased array antenna is a collection of antennas, often called array elements, connected together in such a way as to function as a single antenna (see Figure 2). In a transmit array, the signal being transmitted is split, delayed, and fed to each element. The amount of delay for each element depends on the kind of beam to be formed. Typically, the elements are identical and each have low gain with large beamwidth. When combined together, they form a single high gain beam with a narrow beamwidth. To vary the beam direction, the relative delay between each element must be varied. Therefore, a large number of variable delays is required. Actual variable delays are bulky and expensive, therefore variable phased shifters are often used instead. They approximate the effects of variable delays at the expense of reduced bandwidth. A type of variable delay is the "tapped delay line". A tapped delay line is a set of electrical lines of various lengths that are connected in and out of circuit to form a single line with variable electrical length or time delay.

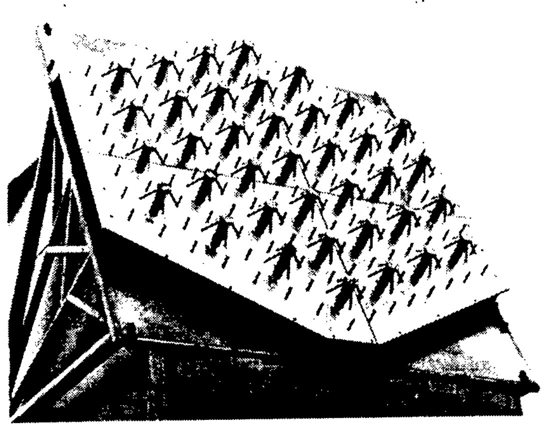

Figure 2. Phased Array Antenna.

1.7.6 Aperture

In antenna terminology, an aperture is the planar surface in front of a phased array or antenna main reflector. It is essentially the projection of the dish or array in a plane perpendicular to the direction of propagation. All the power coming from or going to the antenna is crossing the aperture. For phased arrays, the aperture is typically the same size

as the array itself and parallel to it. This is similar for a symmetric reflector antenna. For an offset reflector, the aperture area is smaller than the dish and the dish is not perpendicular to the direction of propagation.

1.7.7 Hybrid Antenna

There are categories of antenna other than reflectors, lenses, or phased arrays. One potentially useful antenna is the combination of a reflector with a phased array. This is often referred to as a hybrid antenna (see Figure 3). It operates somewhat like a phased array with the reflector acting like a magnifier for a "small" array.

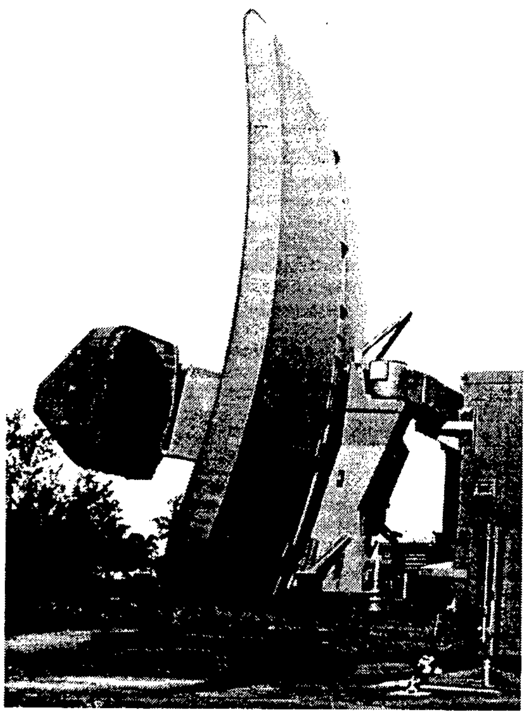

Figure 3. Hybrid Antenna.

1.7.8 Conformal Antenna

A conformal antenna is an antenna that is shaped to conform to some prescribed surface. An example is an aircraft phased array shaped along the contour of a wing so as not to disturb the airflow. On a ship, a conformal antenna could be shaped to conform to the contour of a smokestack.

1.8 Technologies

In selecting the most appropriate technologies for these antenna systems, one recurring debate is the trade-off between reflector antennas and phased arrays. Phased arrays have an almost unlimited potential in area such as multiple beams and agility. However, phased arrays are rarely seen in communication systems because of the one over-riding factor, high cost. In radar systems, where agility is paramount, phased arrays

are common. Radar systems are also more complex and costlier than communications systems and therefore, the ratio of the cost of the antenna to the rest of the system is less. Phased array technology is progressing rapidly, causing phased arrays to come down in price. Because of this, there are signs that more and more communications systems will be using this technology. Table 1 lists the pros and cons for reflector and phased array systems. These pros and cons are not absolute but are valid in general. In this report, reflectors are covered in chapter 3 and phased arrays in chapter 4.

Type	Pro	Con
Reflector	• Inexpensive • Wider bandwidth • More mature technology • Easier to repair	• Bulkier, heavier • Slower beam steering
Phased Array	• Lighter • More agile (fast) beams • Low profile • Conformal • Low weight	• Expensive • Sensitive to internal intermodulation • Difficult to design for wideband and/or multi-band • More susceptible to EMI

Table 1. Reflector versus Phased Array Technology.

2.0 Naval Allied Use of MILSATCOM

This chapter provides a brief overview of Allied use of milsatcom and trends in shipboard terminals.

2.1 UK Naval Use

The UK makes almost exclusive use of military SHF for satcom to its surface ships. The SCOT shipborne terminals were developed for use with the Skynet 4 series of satellites. The SCOT 1 terminal was designed for smaller ships of the Frigate class. Two 1.22 metre antennas are normally positioned on either side of the ship and provide full coverage. The SCOT 2 terminal was designed for ships of about 11,000 tons and upwards, and has a 1.83 metre antenna. A variant of the SCOT has a 1.52 metre antenna, which can be used on a frigate class ship. Two antennas for the SCOT terminal are shown in Figure 4 on either side of the large radar radome. Skynet 4 satellites do have a UHF capability but are used primarily for communications to submarines.

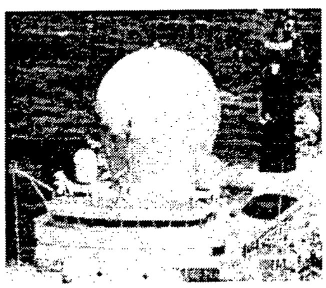

Figure 4. SCOT SHF Antennas.

2.2 UK Naval Trend

The next version of the UK MILSATCOM System is the Skynet 5 which is in the initial definition stage. No definitive decisions have been made, but the initial concept for Skynet 5 is that it will be a dual band satellite with SHF and EHF capability. The SHF capability will be similar to the existing Skynet 4 with some technological advancements. No decision has been made on what the EHF package will look like.

2.3 US Naval Use

2.3.1 Introduction

The US Navy[3] uses three military bands for communication to its fleets, UHF, SHF, and EHF. The Fleet Satellite Communications[4] (FLTSATCOM) System provides most of the capabilities in the UHF band and part of the capability in the EHF band. The Defence Satellite Communications System (DSCS) provides capabilities in the SHF band and Milstar provides extended capabilities in the EHF band. UHF SATCOM is normally used for unprotected low-rate data and voice, SHF is normally used for high capacity communications, and EHF is normally used for highly protected voice and low-rate data.

In addition to the military bands, the US Navy makes use of commercial services, mainly INMARSAT, for low data rate capability.

2.3.2 UHF Terminals

The most common naval UHF terminal is the AN/WSC-3 (Whiskey-3). This terminal has been in-service since 1972 and is used for both line of sight and satellite communications. It provides communications capabilities from 75 bits/s to 9.6 kbits/s. The usual antenna suite used with the terminal is the OE-82/WSC-1(V), and is available in a few variants. The OE-82B and OE-82C are two variants, both consisting of one or two antennas installed on stabilized platforms. The two-antenna installation usually provides better coverage as the satellite is visible by at least one antenna at all times.

2.3.3 SHF Terminals

The most common naval SHF terminal is the AN/WSC-6(V). The terminal is available with a 1.2 metre or 2.1 metre reflector. The system is configurable for both single and dual antenna installations to avoid superstructure blockage during maneuvers or heavy sea conditions. A Raytheon SHF reflector antenna is shown in Figure 5.

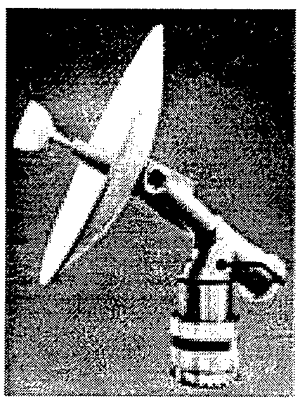

Figure 5. Raytheon SHF Antenna.

2.3.4 EHF Terminals

The EHF terminal used on US Navy ships is the AN/USC-38(V). The terminal is capable of using both the upgraded FLTSATs and the Milstar satellites. The antenna system used with this terminal is the OE-501/USC-38(V). The antenna consists of a 0.88 metre Cassegrain reflector mounted on a three-axis, stabilized pedestal. Two antennas are installed giving full-time view of the satellite. An EHF antenna with radome installed on a stabilized platform is show in Figure 6.

2.3.5 INMARSAT

The US Navy makes extensive use of INMARSAT services, mainly through the INMARSAT A system. Over 240 ships in all major ship classes have been fitted with INMARSAT A terminals. The existing capability provides 9.6 kbps service for high

quality voice, data, and FAX. The 1 metre antenna is housed in a 1.4 metre radome mounted on a stabilized platform.

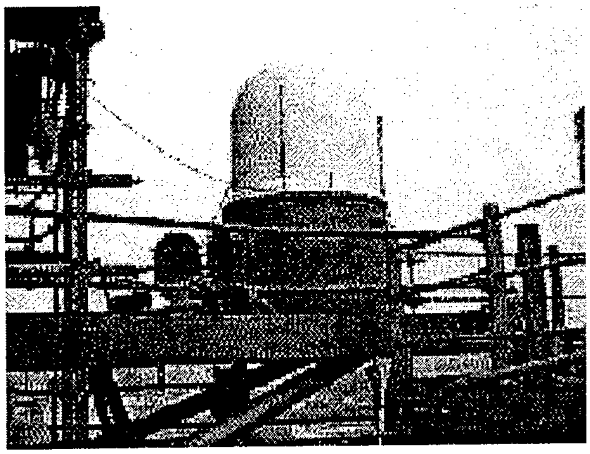

Figure 6. EHF OE-501 Antenna.

2.4 US Naval Trend

2.4.1 Introduction

The US Navy makes wide use of satcom, but each system is independent of the other causing a *stovepipe* problem. As outlined in the Joint Maritime Communications System (JMCOMS) Master Plan[5], an Integrated Terminal Package (ITP) will provide protected, low, medium, and high capacity links in the 2 GHz and above spectrum using military and commercial communications system. In addition, the JMCOMS Slice Radio program will provide a digital modular radio and will satisfy tactical communications requirements in the frequency range of VLF (Very Low Frequency) to 2 GHz.

The JMCOMS Project office will assess existing commercial technology to meet the unique military requirement for multifunction antennas. US Navy ships are currently top heavy with antennas. Multifunction apertures have the potential to reduce topside space and weight, reduce EMI, improve siting for antennas for critical systems, and reduce the ship radar cross section and infrared signature.

2.4.2 AN/USC-38(V) Upgrade

Carriers, flagships and cruisers will receive a 1.4 metre upgrade to provide EHF medium data rate capability. The upgrade will fit within the current Milstar LDR antenna and radome footprint and will retain the same antenna location for most platforms.

2.4.3 AN/WSC-6(V)X Upgrade

This upgrade will provide all flag capable ships with an increase in the antenna to 2.1 metres to support DCSC SHF capability to 1 Mbps.

2.4.4 INMARSAT Upgrade

The INMARSAT A shipboard terminals will be upgraded to INMARSAT B to provide 64 kbps capability to support non-tactical information transfer. INMARSAT M will be installed on ships having little or no satcom capability to provide voice and data satellite connectivity.

2.4.5 Challenge Athena

This objective of this project is to provide a wideband (1.5 Mbps) commercial C-band satcom network capability for multiple access shipborne networks. The shipboard terminal uses a stabilized 2.4 metre reflector antenna.

2.4.6 Multifunction Electromagnetic Radiating System (MERS)

The MERS is a low-cost, lightweight shipboard antenna system that will satisfy the performance requirements of several systems operating in the 200 MHz to 2 GHz frequency band. The main antenna elements are conformal, embedded circular arrays. Work for an advanced technology demonstrator is scheduled to start in US fiscal year 1997 to provide a production antenna systems by fiscal year 2001.

2.4.7 Low Observable (LO) Multifunction Stack

The LO Multifunction Stack integrates satcom antennas and exhaust uptakes into a single lightweight structure. The objective is to include active multi-element phased arrays to provide UHF and EHF MILSATCOM, INMARSAT, and Global Broadcast Service (GBS) capabilities. Funding has been requested for an advanced technology demonstrator for 1998.

2.4.8 Multi-beam, Multi-mission Broadband Antenna (MMBA)

The MMBA is a demonstration program to build and test a single fixed array antenna system for X-band and Ku-band satcom.

2.4.9 Personal Communications System (PCS) over Satellite

The PCS terminal will be a digital based small satcom terminal offering worldwide, low-cost data, message and voice services.

2.4.10 Global Broadcast System (GBS)

The Global Broadcast System (GBS) will provide a broadcast capability that will augment US MILSATCOM and provide high-speed, one-way information flow of high volume data to units in garrison or on the move. Information products will be developed and distributed using a "smart push/user pull" philosophy to avert saturating deployed forces with "information overload". GBS will provide the ability to transmit large volumes of data directly into small antennas.

Phase I (1996-1998) will provide a limited off-the-shelf commercial capability to support selected exercises and concept development. Phase II (1998-2000) will place

packages on UHF Follow-On satellites 8, 9, and 10. Phase III (1999-2001) with provide world wide coverage and achieve objective capability. The Ka-band has been selected for Phase II and III implementation of GBS. The system is capable of transmitting 1.5 Mbps, 6 Mbps, or 24 Mbps (depending on satellite antenna) to 22 inch receive only terminals.

3.0 Multi-Band and Multi-Beam Reflector Antennas

3.1 Introduction

This chapter describes the concepts of multi-band and multi-beam reflector antennas and proposes directions for R&D. We considered only the basic type of reflector antenna where there is one beam per feed. Hybrid antennas (phased arrays with reflectors) are not considered. There is no electronic steering. All the steering comes from an inertial platform and sometimes also by moving the feed(s). In examining the potential for reflector antennas to generate multi-bands and multi-beams, several parameters (or configurations) were examined. They are briefly described below.

3.1.1 Inertial Platform.

All antenna systems were considered to have available an inertial platform for pointing over the sky. In most cases the antenna is protected by a radome. Also, there are usually two identical antennas and platforms to circumvent the superstructure blockage.

3.1.2 Single/Multiple Band.

Antennas can be designed to work with a single set of uplink and downlink frequencies (single-band) or designed to work with more then one (multi-band). Single-band antennas are typically less expensive and may be more efficient as they are optimized for a single-band. Multi-band antennas are typically more complex and expensive but can be used with other satellites.

3.1.3 Single/Multiple Beam.

Ground terminal antennas typically produce a single beam and are therefore able to communicate with only one satellite at a time. However, it is possible to design and build antennas that have more then one beam, and thus allow communication to more then one satellite simultaneously. Although spacecrafts, such as MILSTAR, have demonstrated multi-beam antennas, satcom terminals have not used multi-beams.

3.1.4 Reflector/Lens.

An antenna aperture can be either a reflector or a lens (Figure 7). Reflector and lens technology are closely related in design and operations. The vast majority of all ground terminals use reflector antennas. Lens antennas are typically bulky and are seldom used on ground terminals. In the millimetre-wave range, bulk is less of a problem and the greater scan capability of lenses make them attractive for multi-beam antennas or for antennas where scanning is achieved by moving the feed(s) instead of the reflector.

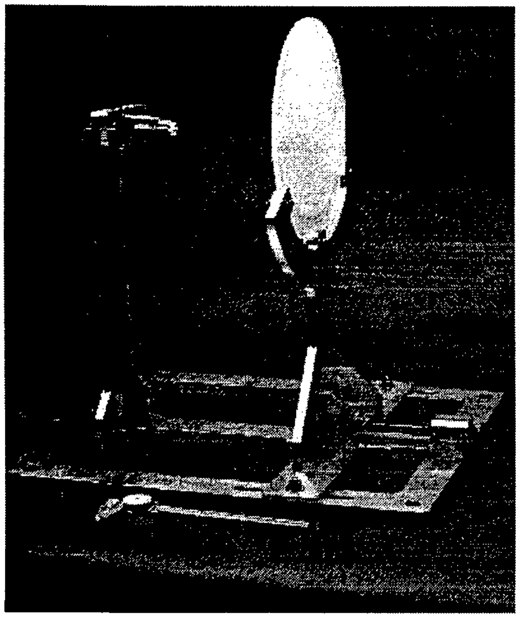

Figure 7. Multi-Beam Lens Antenna Developed by SPAR Aerospace for DREO.

3.1.5 Geostationary/Geosynchronous Satellite.

Commercial satellites are typically in geostationary orbit, that is they appear to be fixed in space from any point on the earth. This means that for fixed ground terminals, once the antenna is pointed at the satellite, it never needs to be readjusted. Military satellites are usually in a geosynchronous orbit, that is they are at the same altitude as the geostationary orbit but the orbit is inclined with respect to the equator. The satellites are typically not station-kept in north-south direction and they have an inclination that can go up to 12 degrees. This means that the satellites appear to move North and South in the sky, tracing a narrow figure eight (Figure 14). This affects the antenna design. Geosynchronous satellites have a north-south movement and must be tracked in that direction. Mobile ground terminals, because of their motion, must track the satellite, therefore there is little if any difference between using geostationary and geosynchronous satellites. In this chapter, antennas have an inertial platform to keep the aperture pointed in the right direction at all time. However, when multi-beams are used for multiple satellites, extra tracking is required to follow the satellites in their limited movements near the geostationary arc.

3.1.6 Single/Multiple Aperture.

Antennas can have single aperture or multiple apertures. Although multiple apertures are more difficult to design and fabricate, there are cases where it is advantageous.

3.2 *Multi-Band Reflector Antennas*

3.2.1 Introduction

Multi-band antennas can be implemented as a reconfigurable feed design, a multi-frequency tuned antenna, or a single wideband antenna. A reconfigurable multi-band antenna has feeds that must be changed when switching from one frequency band to another. The multi-frequency tuned antennas are essentially antennas that have been tuned at several frequencies. A wideband antenna contains all the bands under a single larger band. In some cases, a mixture of multi-frequency and wideband is possible.

There exist a number of reconfigurable multi-band antennas on the market. In all of the designs the feeds must be changed manually or have some degree of automation by repositioning the feeds with motors. This can take from many hours for large antennas with manual designs, to a few minutes with the more automated designs. This method is usually the least expensive. The other two types of multi-band antennas can be reconfigured almost instantaneously. Because this study was concentrating on projecting into the future no investigation on reconfigurable feeds was done.

The current state-of-the-art in more efficient use of space for antenna systems is tri-band antennas: C-band, X-band, and Ku-band. The feeds are manually reconfigured to switch from one band to another. There are a few terrestrial based terminals on the market, with companies like Raytheon designing systems for shipborne use. The size of the reflector is determined by the capabilities of the satellite systems being used, the ITU regulations on off-axis radiation, and the data rate of the communications required. Communications using military UHF systems, INMARSAT, and EHF still require their own antenna subsystems. In the near term EHF and GBS capability may be included in the antenna subsystem, but they would still require manually reconfiguring from one band to another. In addition, the systems are still only single beam antennas so they could only communicate with one satellite system and one band at a time.

3.2.2 Multi-band feeds

Since reflectors usually have very wide bandwidths, the antenna bandwidth is determined by the feed bandwidth. There are 2 main approaches to making multi-band feeds. One is to make a feed with separate bands and the other is to use a wideband feed with a single continuous band. Having separate bands is more advantageous when spacing between the bands is very large. For closely spaced bands, it may be more advantageous to use a wide continuous band feed.

Multi-frequency feeds are typically large and complex. They are difficult to design because of the many conflicting requirements. The beamwidth tends to vary with frequency which creates spillover of the lower frequencies. Also, the phase centre varies with frequency creating defocusing which degrades the beam characteristics. Polarization purity can be a strong limiting factor also because transmit/receive (Tx/Rx) bands are often close to each other and use cross-polarization to increase isolation between the two bands. It is also possible that the weather affects polarization purity by building ice on the

feed. Another problem that increases with the amount of transmitted power is passive intermodulation. All these factors can make multi-band feeds quite difficult to design and very costly. It is not surprising that the tri-band terminals available today use separate feeds.

K.K. Chan et al[6,7] (Figure 8) designed a tri-band feed for DND with dual polarization for each band. The feed provides simultaneous multiple frequency receive capability at C, X, and Ku band. Moreover, it offers dual polarization (circular or linear) in each band to form a six-port device. The feed was tested on a 13m Cassegrain dish. Crosspolar isolation was found to be better than 30 dB. The penalty for combining 3 bands on a single horn is a very large and complex feed. The R&D cost to design and build this feed was around 1 million dollars. For different bands, most of that effort would have to be redone so that the cost would probably not be significantly less.

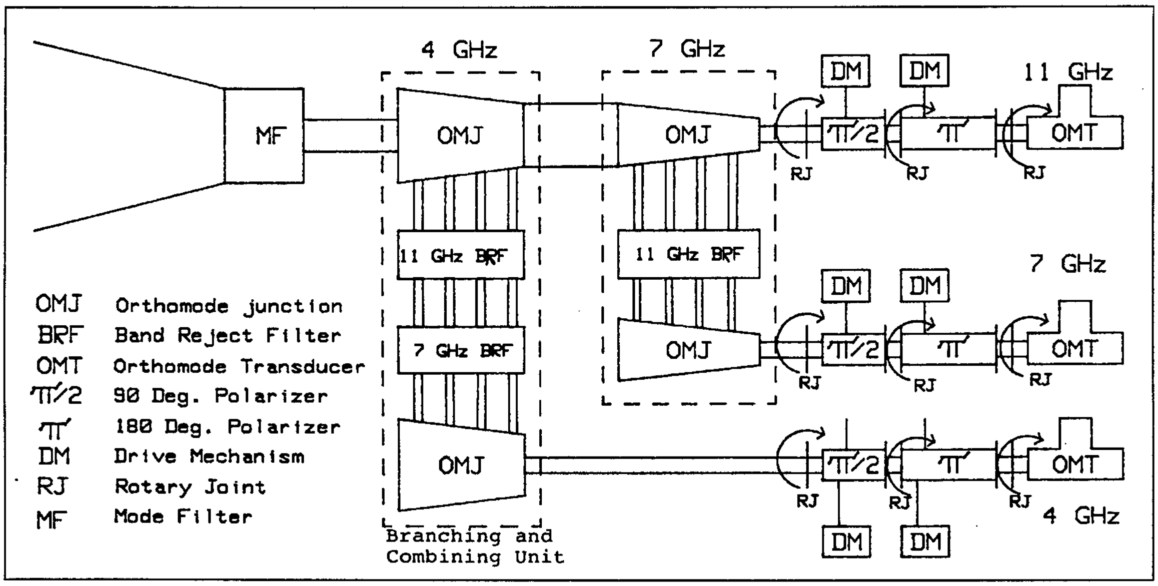

Figure 8. Triband Multiplexed Feed with Full Polarization Diversity (by K.K. Chan).

A very wide band feed with good potential for space communications was presented by Burnside et al.[8] and Chang[9] and Burnside. They call this feed an "R-card version of the Slotline Bowtie Hybrid (Rcard-SBH)". It has a bandwidth of 1 to 18 GHz. The main advantages, other than ultra-wide bandwidth, are stable beamwidth, stable phase center, dual polarization, ease of fabrication and low cost.

Other wideband feeds are:

- double-ridged horn
- quad-ridged horn
- log-periodic antennas (single or dual-polarized) and its numerous variations
- cavity-backed spiral
- spiral antenna and its numerous variations
- conical- and spiral-helix antenna

3.2.3 Frequency Selective Surface (FSS)

A very common approach for obtaining multi-bands in a single beam uses frequency selective surfaces (FSSs) for making the subreflector [Rusch[10]]. An FSS is a surface that reflects one frequency but transmits another. Several FSSs can be used to accommodate more bands. Each band is served by a single feed that can be dual-polarized. In this approach, the feeds are simpler and less expensive to design compared to the multi-band feed but some effort must be spent in designing the subreflector(s). Figure 9 shows a diagram of a 3-feed reflector using 2 FSSs. Another advantage of using an FSS is that it is often desirable not to have transmit and receive in the same feed if large amount of power is being transmitted. It is possible to obtain more isolation with an FSS than with a multi-band feed.

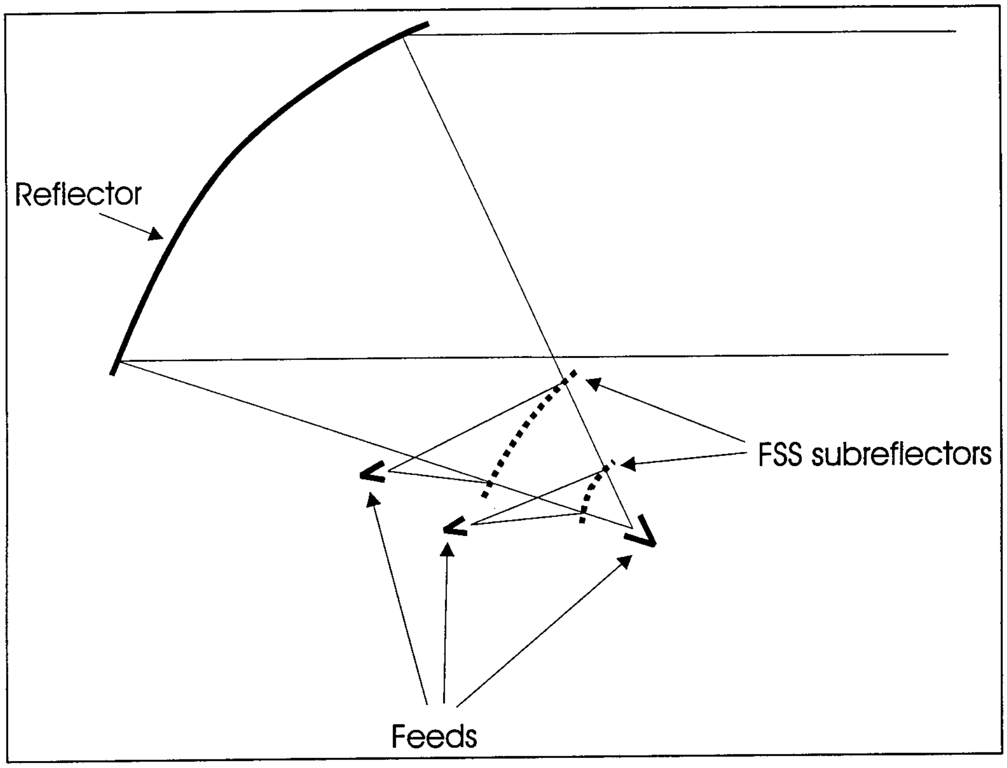

Figure 9. Multi-Band Reflector Antenna with 2 FSSs and 3 Feeds.

The FSS approach usually requires that the reflector be offset to reduce obstruction. This is not always desirable for mechanical reasons. Also there is more loss due to transmission and reflection through the FSSs. However, better isolation between Tx and Rx bands can be achieved.

3.3 Multi-Beam Reflector Antennas

3.3.1 Introduction

Multi-beam antennas for satcom terminals have not really been used before. The main reason is probably that the need was not strong enough to justify the R&D cost. However, with the advent of more and more satellite services, there is a much stronger incentive to start reviewing options for accessing several satellites simultaneously from one antenna. Two such options are proposed here.

Usually, a reflector antenna has a feed located at the focus. However, the feed can be moved away from the focus in a plane normal to the focused feed axis and still provide a useful beam. The resulting "scanned" beams (Figure 10) are pointed in a direction different from the original direction ("boresight direction"). The price to pay is reduced gain and higher sidelobe levels. This beam scanning ability can be extended to 5 or 10 beamwidths off boresight. Therefore, several feeds can be used for the same reflector (see e.g. Figure 11). The numbers of beamwidths depends on how much degradation can be tolerated. Typically, 5 to 10 beamwidths off boresight can be achieved with typical parabolic reflectors. However, spherical reflectors can achieve wider scan at the expense of a larger reflector and higher sidelobes. Thanks to this scanning ability, several feeds can be used to point at several satellites. However, one important disadvantage of this approach is that, to avoid feed obstruction, the reflector must be offset. This could impose extra weight or torque on the inertial platform.

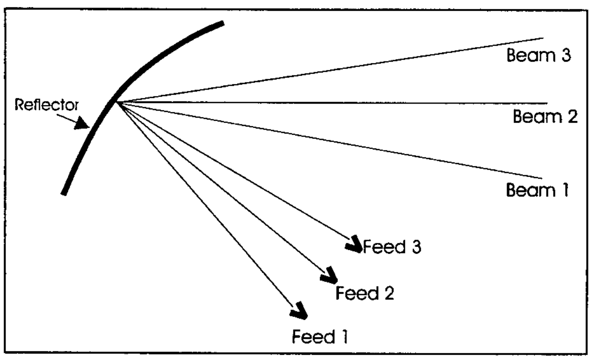

Figure 10. Three-beam Reflector Antenna.

3.3.2 Designs

The inertial platform of a terminal antenna keeps the antenna pointed at a fixed point in the sky. This is the mechanical boresight. Because of the scan ability of reflectors, it is possible to replace the single feed by several feeds in the antenna focal plane and obtain several simultaneous beams (Figure 12). The platform would point the mechanical boresight somewhere in the "middle" of the satellite cluster. The feeds would be positioned to aim directly at the satellites of interest.

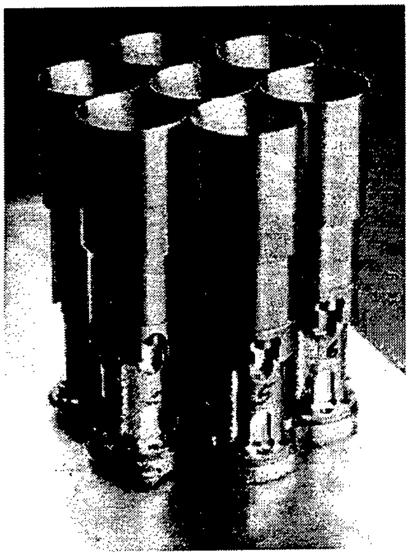

Figure 11. Feed Array For a 7-Beam Multi-Beam Reflector Antenna Designed by Spar Aerospace for DREO.

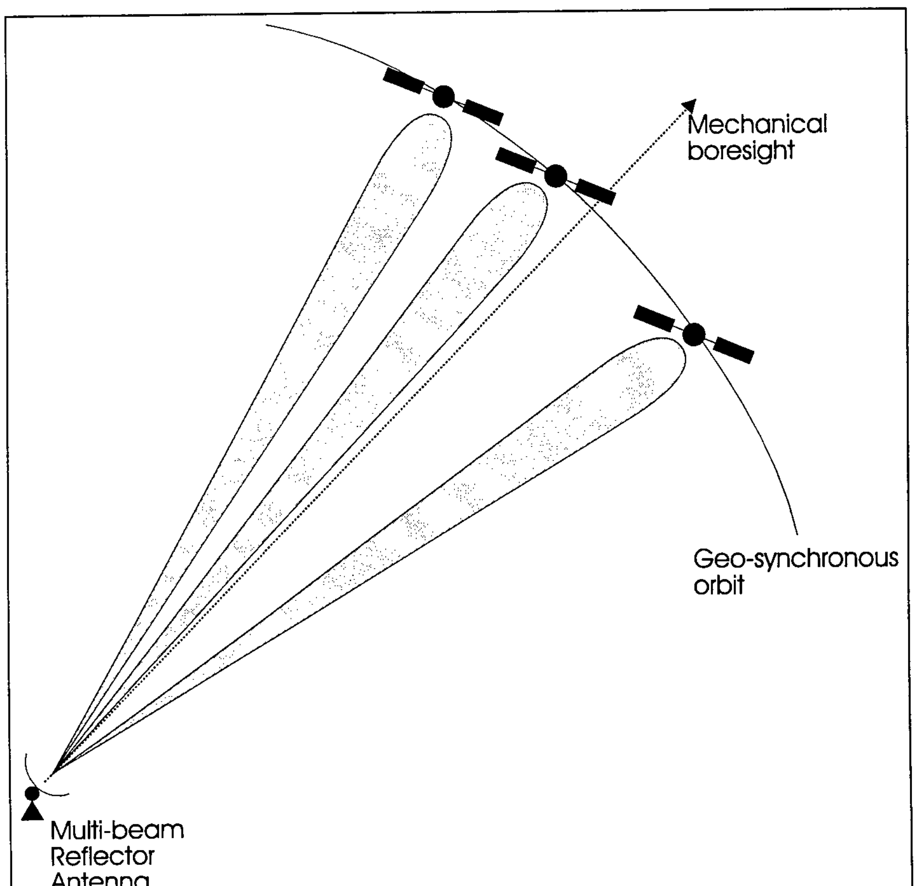

Figure 12. Three-Beam Reflector Antenna Showing the Boresight Direction.

Because of the limited feed scanning, only geosynchronous and geostationary satellites could be tracked. Satellites in other orbits, such as Molnyia or low earth, typically have too much motion to be tracked from a single reflector.

The two main R&D challenges are the design of the feeds and the feed tracking system. Two general types of designs will be described: non-reconfigurable and reconfigurable systems.

A non-reconfigurable design is possible for communications to multiple geostationary satellites if the satellites are in fixed positions with respect to each others and this configuration will not change with time. In this case, the feeds are arranged in fixed positions and generate beams along the geosynchronous arc. On a ship with a 2-axis inertial platform, the system points boresight at a pre-planed point of the arc. All the beams would then point at their pre-assigned satellites if the ship were perfectly still and horizontal. However, the movement of the ship creates a rotation of the beams around boresight (Figure 13). A third axis is then required to align all the beams with the satellites. This third axis can be a roll axis that is normally used to rotate polarization. If a third axis cannot be easily provided it may be more advantageous to move the feeds. They are much smaller components and will require much smaller motors than trying to add a full-size 3rd axis on the inertial platform. If a 3-axis inertial platform is provided, it is probably sufficient to provide full tracking but the positioning controller must learn a new algorithm to track all the satellites as well as keeping the feeds aligned with the geostationary arc. The main R&D concerns in this approach are the controller algorithm, the reflector design if wide scanning is required, and the feed designs if some beams overlap at –3 dB or more.

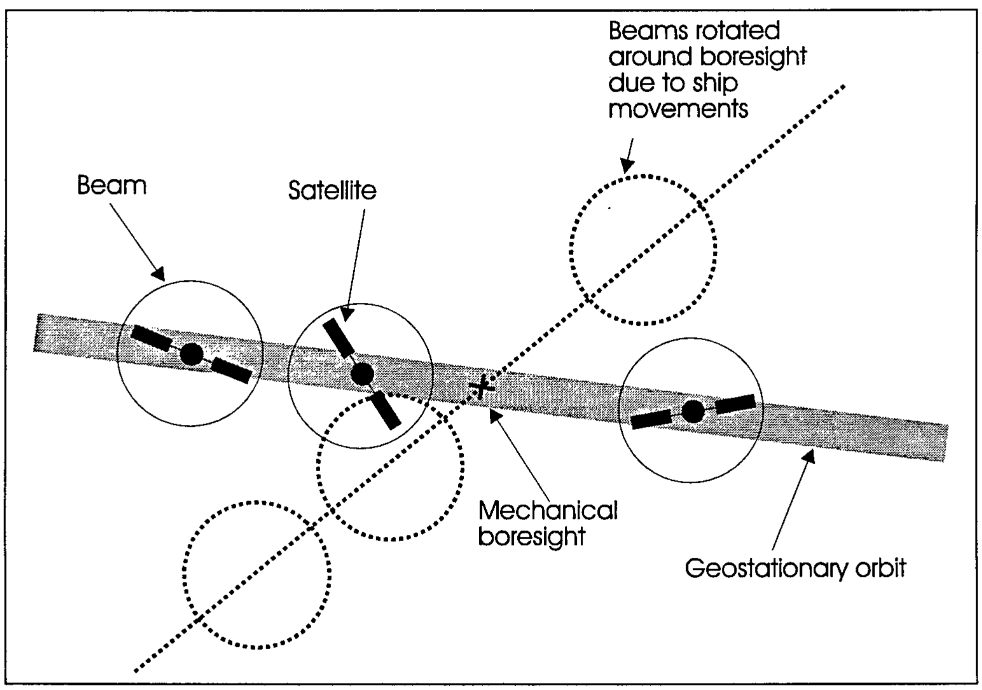

Figure 13. Beam Rotation Due to Ship Movements.

When the satellites to communicate with are not in fixed positions because of north-south movements or simply because we want the option to communicate with a subset of a larger set of satellites depending on needs, a reconfigurable architecture is required. Because of the limited scan capability of reflectors, it is possible to track geosynchronous satellites that have only limited north-south movements. As in the previous configuration, an inertial platform points the mechanical boresight to the center of the satellite cluster to communicate with simultaneously (Figure 14). The rest of the tracking is performed by moving the feeds in the focal plane. Every feed needs to track independently. Typically, not a lot of movement is required, only few degrees along one line. If it is desirable to have feeds that can point to different satellites, it becomes imperative to take care of collisions between feeds as one feed is moved to a new position. This will restrict feed design substantially. However, by selecting feed designs very carefully, it might be possible to avoid collisions altogether but not obstruction. Also because of feed sizes, it is not possible to have overlapping beams (within approx. –3 dB). Therefore, if 2 satellites are very close to each other, they cannot be seen from the same reflector. Taking everything said into consideration, it seems that a three-beam reflector antenna is quite feasible. More beams would become increasingly difficult and less advantageous mostly because of increased obstructions and therefore, more limited use.

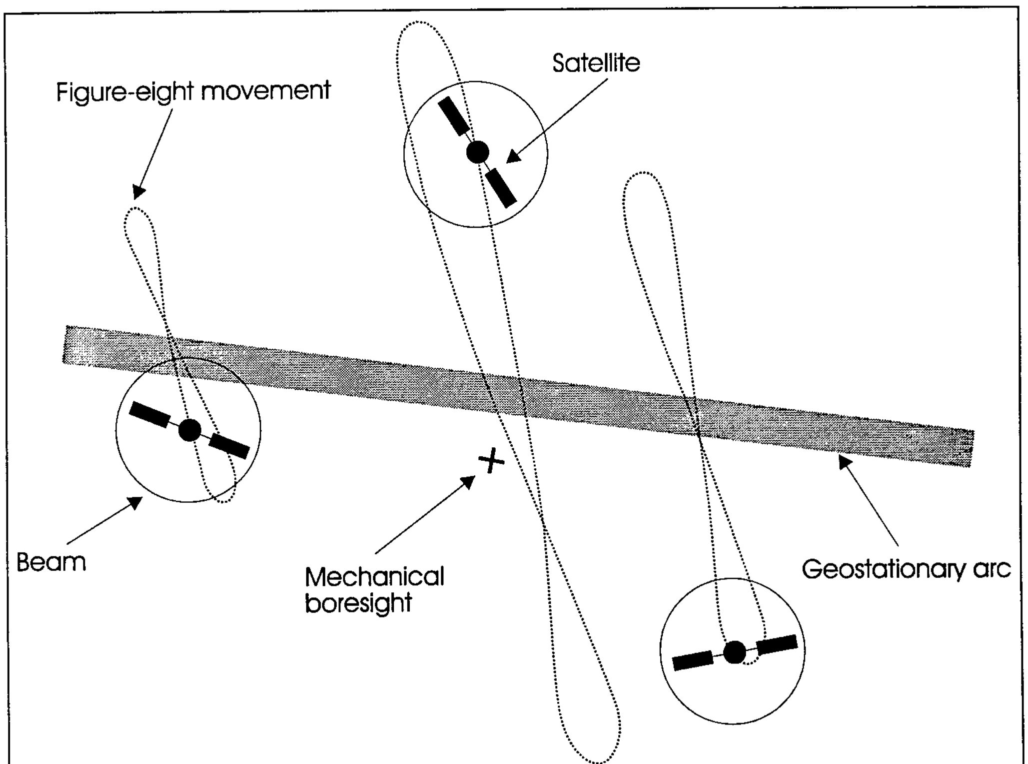

Figure 14. View of Satellites and Beams in a Reconfigurable System.

3.4 Multi-Band & Multi-Beam Reflector Antennas

Combining the two approaches of multi-band and multi-beam is a more difficult design problem but can provide much increased capability. Multi-band feeds can be much larger than single-band feeds and the problem of collision between feeds while tracking more then one satellite becomes even more acute. However, the benefits can be quite substantial. For instance in a best case scenario, three tri-band feeds could potentially access three satellites with three different services from each satellite for a total of nine simultaneous services.

3.5 Multi-Aperture Antennas

There are several ways that multiple apertures can be combined to increase bandwidths, the number of bands, or the number of beams. In some cases, it is difficult to decide if it is a multi-aperture antenna or multiple antennas. We will not try to argue this distinction. We will show one way to increase the number of bands.

Small apertures or boom-like antennas can be attached to a large reflector without seriously affecting the stability of the inertial platform (Figure 15). The lower the gain and the higher the frequency band of interest, the smaller the attached antenna is and the more attractive the solution becomes. Typically, the integration of 2 apertures is mostly a mechanical problem. However, there is always the possibility of interference between the apertures. Careful design or positioning may be required. The main advantage of a multi-aperture approach is the sharing of a single inertial platform.

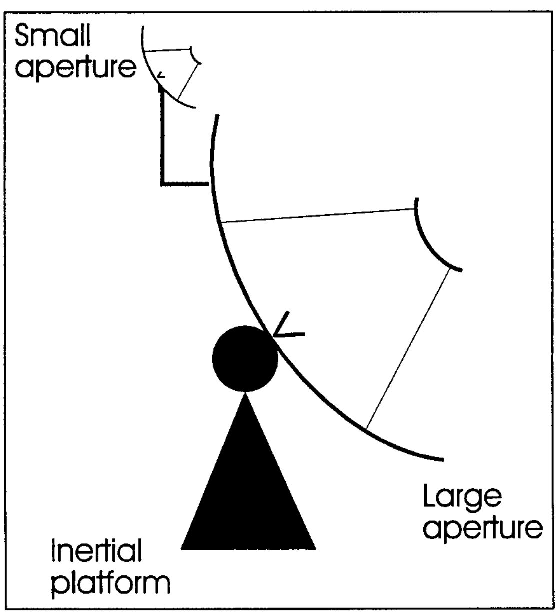

Figure 15. Two-Aperture Antenna.

In Figure 15, there are 2 bands, one from each antenna. However, if extra movement was provided to the small aperture, it would be possible to have a separate beam for tracking a satellite near the one pointed at by the inertial platform.

4.0 Phased Array Technology

4.1 Introduction

Phased array antennas keep attracting a lot of attention in the R&D community because of their great potential. In applications were beam agility is critical, such as agile radars, no other technology can compete. In addition, conformal applications or mobile applications requiring low weight and low profile are natural uses of phased array technology. Unfortunately phased array antennas are expensive and can cost one or two orders of magnitude more than reflector antennas. To date only a few applications have been able to absorb the extra cost of phased array technology, such as radar systems. However, as R&D drives the cost of the technology down, more and more applications will become affordable. It is anticipated that conformal applications, such as fitting an antenna to an aircraft wing or fuselage, will be one of the first communications uses of the technology.

The trade-off between reflectors and phased arrays depends very much of the time-scale one has in mind. Certainly, in the short term (less than 2 years), there are few cases where a phased array would be justified for communications especially on a ship. In the long term (10 years or more), phased arrays will have come down substantially in price and more applications will become affordable. One possible cost reduction is a phased array without electronic steering which can compete with reflector antenna but they need the same stabilized platform as reflector. The use of a stabilized platform precludes another important advantage of phased arrays: conformal capability. Therefore, to have a conformal phased array electronic steering is necessary, which increases the cost dramatically.

4.2 State-of-the-Art

The main factor driving the cost of a phased array is the number of elements. As a rough order of magnitude in determining the cost of a phased array, it can be said that the cost is proportional to the number of elements, N. However, the gain is also proportional to N which makes the cost proportional to the gain. Therefore, large beamwidth can be much less expensive and even affordable in cases of low gain applications. Another important factor in the cost is the bandwidth along with the amount of steering (in beamwidth) required. For narrowband operation and/or limited steering, phase shifters are sufficient but for wideband and/or large steering, tapped delay lines are required. For instance, for a wideband phased array scanning 60° in all directions, the tapped delay lines will be as long as the array itself. If this is a high gain phased array, it may have thousands of elements, and each element will have a tapped delay line with an electrical length comparable to the full array size. It is obvious that space becomes a major concern.

One way to characterize phased arrays is according to their scanning ability, full scan, limited scan, or no scan. When a full scan ability is required, the element spacing is usually close to a half wavelength and the number of elements is the largest for all the

categories. When limited scan ability is acceptable, it is possible to use larger elements and therefore reduce the number of elements for the same array surface area (and gain). This reduces significantly the cost. Another good approach for limited scan ability is to use a small array with a reflector or lens aperture. This also reduces the cost because of the smaller number of elements. A third approach for limited scan is the use of thinned phased array where a smaller number of elements are distributed, often at random, over the array surface. The cost is reduced because of the smaller number of elements but scanning is reduced because of the appearance of grating lobes (large isolated sidelobes reducing the main beam gain) when scanning too far from boresight. Finally, when no scan is required, a much less expensive phased array is possible. The main reason why these type of arrays are use is for conformal antennas, where the shape factor is very important and a reflector cannot be used. Sometimes, the array can also be lighter than an equivalent dish.

Multi-beam phased arrays are very attractive for radars because of their capability to form very agile beams. For communications, 2 to 4 beams would be quite attractive. A substantial part of the phased array has to be duplicated for each required beam. Although, for instance, a 4-beam array does not require 4 times the number of components required for a single beam array, the number can be quite large. The number of radiating elements does not change with the number of beams but all the circuitry behind does. The problem of fitting all these components in a very tight space grows very rapidly. The difficult problems are heat dissipation and inter-layer connectivity.

Providing multi-band operations within a single octave (ratio of 1 to 2 between lowest and highest frequency) of bandwidth is feasible in principle by using wideband components. On the transmit side, using multiple carriers can be quite detrimental to the channels by generating spurious signals. For bandwidth larger than one octave, a new problem surfaces. The radiating elements have to be made small enough for the high frequencies but have to be combined for the low frequencies.

Reid[11] gives a survey of phased array technology for fighter aircraft. Much of the same technology is used for ship applications. The electronics technology is quite similar but the size and packaging of the arrays can be quite different probably to the advantage of the ship.

A substantial amount of research is being devoted in exploring optical techniques to reduce the cost of full-scan wideband arrays. Optical techniques may offer advantages in three areas; better implementation of true-time-delay (actual delay instead of phase shift), lower weight, and immunity to radio frequency interference (RFI).

Digital beam forming is the approach taken where each individual element signal in a received phased array is digitized than processed numerically. Therefore, the number of elements would not grow with the number of beams. With this approach, it is possible to form as many beams as required, steer them independently in any direction, shape them, and adaptively modify them. The processor cost and size grows rapidly with capability of the beams. Also, digital beamformer are advantageous with conformal arrays because the beam forming is more difficult because of the form factor.

For applications where only one beam is required, a less expensive future solution may be possible with ferroelectric materials. A ferroelectric material is a dielectric (usually a ceramic) that changes permittivity through the application of a DC electric field. It is possible to imagine designs of phased arrays that can be steered in two-dimension only with the application of two DC biases. This technique is the ultimate in simplicity. One limitation of this approach is that only one beam can be produced. However, all ferroelectric material known to date exhibit very high losses which makes phased arrays of more than a few elements impossible. There is no low-loss ferroelectric material in sight. Ferrite material could be used in principle to design simple one-beam phased arrays. However, they suffer from problems similar to those of the ferroelectric approach.

4.3 Future Directions

In the next few years, the most likely application of phased arrays on ships would be as low gain antennas (large beamwidths). Such antennas require few elements (up to few hundreds) and would not be prohibitively expensive. With more powerful satellites being deployed, terminals require lower gain antennas making phased arrays interesting. If the number of elements is small enough, it is even feasible to consider multi-band and/or multi-beam.

One of the interesting designs for shipborne applications requires 4 phased arrays working together to form an antenna. Each phased array can cover at most 60° in every direction from array boresight. Therefore, one phased array on each side of the ship will cover the whole hemisphere. An option would be to incorporate the phased array into an existing structure such as an exhaust stack such as proposed by the US Low Observable Multifunction Stack (see para 2.4.7). On the CPF (Figure 1), the smokestack has 5 large flat surfaces that might be used to install phased arrays.

5.0 R&D Plan

In developing an R&D plan, we focused on identifying areas where Canadian industry is competitive or there is a unique Canadian naval requirement. There are many potentially niche areas that are unlikely to be fully addressed by industry or other allied militaries. One niche area is in the custom selection of services. Because of the great variety of actual and upcoming services, each ship or class of ships may require a selection of services that would not be provided by off-the-shelf terminals. Another niche area is in multi-band and multi-beam terminal antennas for small ships.

This report has investigated a number of emerging R&D areas in satellite communications technologies. These included medium-term areas in reflector technologies and long-term areas in phased arrays. The previous chapters have identified possible R&D areas in both reflector and phased array technologies. These are summarized in Table 2 below. Also shown in the table is some indication of the time frame required to develop the technology for a specific application.

Functionality	Reflector (or lens)	Phased Array
Single-band, single-beam	current technology	3 years & up
Multi-band	1 to 5 years	5 years & up
Multi-beam	1 to 3 years	5 years & up
Multi-band and multi-beam	3 to 7 years	7 years & up

Table 2. R&D Antenna Technologies.

The R&D required is very dependent on the exact application. Depending on the specifications required to meet an application the cost can easily vary by an order of magnitude or more. For instance, the cost of developing a tri-band reflector antenna could require between $100K and $1M, depending on the bands of interest, bandwidths, polarizations, cross-polarization characteristics, and isolations. At today's level of technology development, phased arrays would typically be an order of magnitude more expensive than reflectors. Again, small changes in the specifications can make a large difference in the cost of the array.

DREO has been involved with multi-beam reflector and lens antennas for the past 10 years. We have an anechoic facility for antenna measurements from 2 to 46 GHz, with a spherical near-field system and a planar near-field system. We also have cooperative agreement with CRC for antenna design. They have been involved, in the past 8 years, with various kinds of antenna designs including planar antennas and phased arrays. CRC and DREO are commencing a joint activity in the application of phased arrays for military applications.

The recommendation is, in cooperation with naval requirements and engineering personnel, to identify the specific needs of the Navy for future satcom antenna requirements. Some of the areas to be defined should be the specific ships which require satcom terminals, the size of antennas subsystems that could fit on these ships, the

frequency bands on interest, the data rates required, and the time frame of interest. Other critical parameters will no doubt also be identified. The purpose is to identify what specific technologies need to be in place to satisfy Navy satcom applications.

6.0 Conclusion

The commercial industry has brought the capabilities of satellite communications around the world through such systems as INMARSAT and INTELSAT. Industry has also provided terminals at an affordable price to the civilian market. What is missing from the equation are the unique military requirements that are not satisfied by what is available today from industry or our allies.

The Canadian Navy will require more and more satellite services in the foreseeable future. These services must fit on the existing fleet with ships that are typically much smaller than those of our allies. Therefore, it is imperative to use the available above deck space more efficiently. This can be achieved by combining several bands and several beams in the same antenna platform. Multi-band and multi-beam terminals have not been investigated much in the past. The present tri-band terminals have 3 separate feeds that can be mechanically interchanged depending on the user request. Unfortunately, this takes time. One would like to be able to just select the band from the terminal keyboard. There are many cases where it would be advantageous to use more than one band simultaneously. Multi-beam terminals are mostly non-existing although the need is now growing and has been identified by the US Navy as an R&D requirement.

Over the last 10 years DREO, in cooperation with CRC, has developed a substantial amount of experience in reflector (and lens) antennas. In addition, a new cooperative R&D program in EHF phased arrays for military applications is commencing. To ensure that the existing and future R&D activity is focused to support specific user needs constant dialog between the users and CRAD personnel is mandatory. Additionally, because of the relatively small size of the R&D budget in comparison with our allies, the R&D areas must be carefully chosen to complement commercial and allied work.

7.0 References

[1] P.E. Law, "Shipboard Antennas", Artech House, 1986.

[2] P.E. Law, "Shipboard Electromagnetics", Artech House, 1987.

[3] J. Williamson, "Jane's Military Communications", Seventeenth Edition 1996-1997.

[4] D. H. Martin, "Communications Satellites", 1958-1995, The Aerospace Corporation, 1996.

[5] Space and Naval Warfare Command, "Joint Maritime Communications System (JMCOMS) Master Plan", PMW 176, Department of Defense, 10 September 1996.

[6] K.K. Chan, S.R. Gauthier, G. Dinham, "Multifrequency Band Earth Station Feed Design", 1990 Antennas and Propagation Symposium Digest, pp. 960-3, Dallas, Texas, 1990.

[7] K.K. Chan, "Design of a Wideband Multifrequency Dual Polarization Feed System for a Dual Polarization Feed System for a 13m Cassegrain Earth Station - Final Report", submitted to CSE (DND), DSS file no. 5MH.12213-5-5102, March 1996, 115pp, Ottawa, Canada.

[8] W.D. Burnside, L-C. T. Chang, B. Smith, "An Ultra Wide Band Low RCS Antenna for Chamber Applications", AMTA Seventeenth Meeting and Symposium, Williamsburg, Nov. 1995.

[9] L-C. T. Chang, W.D. Burnside, "A Novel Dual-Polarized, Ultrawide Bandwidth Horn Antenna", Eighteenth Annual Meeting & Symposium Antenna Measurement Techniques Association, pp. 109-11, Seattle, Sept. 1996.

[10] W.V.T. Rusch, T.S. Chu, A.R. Dion, P.A. Jensen, A.W. Rudge, W.C. Wong, "Quasi-Optical Antenna Design and Applications", in "The Handbook of Antenna Design" by A.W. Rudge, K. Milne, A.D. Olver, P. Knight, p. 184, 1986.

[11] M.A. Reid, "Active Phased Array Antenna Technology for Fighters", Canadian Forces School of Aerospace Studies, document no. 4640-7-2 (ASC), CFB Winnipeg Westwin, Manitoba, Canada, 25pp, Apr. 1996.

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The purpose of this report is to document a study commissioned to Defence Research Establishment Ottawa (DREO) by Director Maritime Ship Support (DMSS) in the area of future naval satellite communications (satcom) for the Canadian Navy. The study investigated possible technology gaps in the area of satellite antenna systems for military applications, concentrating on the difficulty of installing large antenna systems on smaller size ships.

With the advent of numerous new satellite services, both commercial and military, and the merging of the communications media (information highway), the demand for more satcom capacity on ships is increasing rapidly. Because of the limitations in size and weight, several bands and several beams could be integrated together in a single antenna platform. All these signals would be connected (remotely) to various terminals dispersed across the ship. Reflector antennas and phased array antennas are the two main technologies to help achieve this goal.

The present state-of-the-art for reflectors and phased arrays in the area of multi-band and/or multi-beam is not mature yet. The major limitations are cost and complexity. However, since this area has become popular only recently, there is ample room for rapid improvements and possible breakthroughs.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

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